Cypriot and Greek Army Military Boot Cushioning: Ground Reaction Forces and Subjective Responses

Panagiotis Paisis[1], Brian Hanley[1], Konstantinos Havenetidis[2], Athanassios Bissas[1]

[1]*Carnegie Faculty, Leeds Metropolitan University, United Kingdom*
[2]*Faculty of Physical and Cultural Education, Hellenic Army Academy, Greece*

Abstract

Lower limb injuries are a continual and serious issue for military personnel. Such injuries have been associated with the requirement to train in military boots (MBs) and might be offset with commercial insoles. In this study, ground reaction forces were measured in seven male participants wearing running shoes (RS), MBs commonly used by Cypriot and Greek Army personnel, and the MBs with two types of shock-absorbing insole. The participants performed 4-min trials at walking pace (5 $km \cdot h^{-1}$) and running pace (10 $km \cdot h^{-1}$) at a 5% gradient on a treadmill under all four shod conditions. The treadmill incorporated two force plates under its belt, which provided measurements of key kinetic variables. During walking, RS showed significantly lower values for impact peak force ($p < 0.01$), maximum force ($p < 0.05$), and push-off rate ($p < 0.05$) compared with other conditions, although no significant differences were found during running. Although the RS were rated significantly more comfortable than any other condition, neither insole made the MBs more comfortable to wear. With little evidence to support wholesale adoption of insoles in MBs, their use by military personnel can only be recommended on a case-by-case basis.

Introduction

Overuse injuries of the lower extremities associated with military training are a serious and continual problem, resulting in loss of manpower and training time.[1-4] The majority of musculoskeletal injuries associated with military training occur at or below the knee.[5] For example, Havenetidis et al[4] found that the most common injuries in Hellenic Army Academy recruits were to the ankle and foot. It has been suggested that the typical military boot worn during training may be a factor in these injuries, due partly to the inadequate cushioning they provide against shock transmission through the tissues of the lower limb.[6] This is because the main role of military boots is to protect the foot from direct trauma (due to rough terrain, for example)[1] and protect the ankle from inversion injury[7] rather than providing shock absorbance. However, previous research has suggested that impact forces were decreased in military boots when using an additional insole[8] and that by using such insoles the incidence of injuries can similarly be decreased.[2] This is interesting given that athletic footwear and shock absorbing insoles are often used by the civilian population to try to protect against injury[9] by reducing the magnitude and rate of loading experienced during walking and running.[10] However, other research has found that there was no benefit gained from using additional insoles in military boots,[1,11] particularly when running[12] and so their value to army personnel is still unclear.

While some studies have taken an epidemiological approach in assessing the role of insoles in reduction of injury risk,[11,13,14] others have directly measured those factors associated with lower limb injury. For example, in comparing a standard British military boot with and without a commercial insole, Dixon[15] used a force plate to measure ground reaction forces (GRF) from the right foot only during running trials along a 15 meter runway. She found that peak impact force and peak rate of loading were both significantly reduced when using the insole. Similar experimental set-ups were adopted by Dixon et al[8] and O'Leary et al[16] but a limitation of measuring kinetic variables in walking or running is the difficulty of obtaining multiple footstrikes. This is because normal gait patterns, and consequently GRF curves, can be affected by participants targeting the force plates rather than walking or running naturally at an appropriate, realistic pace. This drawback can be avoided with the use of an instrumented treadmill with in-dwelling force plates located under the treadmill belt. Such treadmills also have the advantage that running or walking speed can be controlled and multiple steps can be measured during a single trial. These treadmills are not widely available and therefore offer a novel approach to analyze the effects of military boots on GRFs.

Although all Cypriot and Greek men are normally required to attend the Army forces for a period of between one and two years, few published data exist related to the shock properties of the military boot that is used by Cypriot and Greek Army personnel. Army personnel might decide to use commercially available insoles as a means of protecting themselves from injury or pain. However, despite the enormity of the problem as reflected by the high incidence of lower limb injuries during basic training,[4] no studies have examined the possible beneficial effects of improving shock absorption in military boots in Cypriot and Greek Army personnel. Therefore, the principal aim of this study was to investigate the GRFs generated during walking and running on an instrumented treadmill while wearing running shoes, military boots (MB) commonly used by Cypriot and Greek personnel, and MB with two different shock-absorbing commercial insoles in an attempt to understand the possible internal loading mechanics. The present study aimed to investigate the importance of comfort perception under these footwear conditions and how this information related to GRF data. Due to the employment of the instrumented treadmill, the findings of the study would provide valuable information not only to Cypriot and Greek Army personnel but to other users of military boots.

Methods

Participants

Seven healthy young adult male volunteers (24 ± 3 years; 1.73 ± 0.06 m; 79.2 ± 9.4 kg) took part in the study. The participants wore light clothing and were barefoot during the measurement of their anthropometric characteristics. All participants were normally heel-strikers, free from injury on the day of testing, and experienced in treadmill running. The study was approved by the University Ethics Committee and written informed consent was obtained from all participants prior to participation in the study.

Description of the boot and insoles

The standard MB is a rigid boot composed of an upper made of leather and a rubber sole and its mass (individually) is 0.90 kg. This particular MB is used by Cypriot and Greek Army personnel (infantry). Two commercial pairs of insoles from different manufacturers were used in the present study. The specifications of the insoles are presented below:

Insole A: An Ethyl Vinyl Acetate (EVA) insole, featuring a forefoot to aid flexibility and increased EVA heel thickness for comfort. It also has a sculpted heel area for support, an anti-slip texture on the underside for grip and a toweling top surface for comfort.

Insole B: This insole was developed using Sorbothane™ technology and consists of 100%

polyurethane foam for cushioning, and covered in breathable polyester fabric to wick away moisture.

Procedure

The research took place at the University Campus (Biomechanics Laboratory) where participants performed a test comprising both walking and running on the h/p/Cosmos Gaitway treadmill (Gaitway, Traunstein). This treadmill has two in-dwelling force plates with an eight-channel charge amplifier (Kistler, Winterthur) which can measure GRFs during locomotion. Its force range was set to 6000 N for testing. All participants were given time to familiarize themselves with the treadmill during a separate visit. This was achieved by allowing the participants to walk and run on the treadmill at any desired speed for any period of time.

Each participant performed a warm-up at a steady pace. Afterwards, they performed stretching exercises of their preference. To imitate the kinds of training undertaken using the military boots,[3] the participants then started either walking at 5 $km \cdot h^{-1}$ (1.39 $m \cdot s^{-1}$) or running at 10 $km \cdot h^{-1}$ (2.78 $m \cdot s^{-1}$) on the treadmill, at a 5% gradient, for 4 minutes. Each test was performed under the following conditions:

- Wearing running shoes (RS)
- Wearing the MB without insole (MB)
- Wearing the MB with insole A (MBA)
- Wearing the MB with insole B (MBB)

The order of testing was randomized to imitate the undefined nature of training and between each condition the participants had a rest of 4 minutes. It was decided to conduct each running and walking trial over 4 minutes in order to minimize any possible influence of fatigue over the course of testing and to minimize any discomfort felt in any particular shod condition. The participants wore their own running shoes, while the boots and both sets of insoles were newly acquired. Data were collected at 1000 Hz during the last 30 seconds of walking and running in all four different conditions. This resulted in analysis of between 50 and 60 steps during walking and between 70 and 90 steps during running per participant during each condition. During data collection, the researcher ensured that each participant was striking the treadmill correctly; this was achieved by monitoring the participant's position on the treadmill and by checking that a full complement of force traces were recorded immediately after recording. The treadmill collected data from both left and right footstrikes. The kinetic variables that were collected and investigated included the impact peak force (IPF), the push-off rate (POR), maximum force (MF) and loading rate (LR). IPF was defined as the as highest recorded force recorded during the first 70 ms of contact with the treadmill and represented the passive peak. In conjunction with this, MF was defined as the highest force recorded during the contact phase. LR was defined as the slope of the force curve throughout the loading phase of the running cycle and is taken from the point of 10% of the IPF to the 90% point. POR was defined as the slope of the force curve during unloading, taken from the 90% of push-off peak to the point of 10%. To facilitate comparisons between participants, GRF peak magnitudes and loading rates were divided by the participants' weights and expressed in bodyweights (BW) and bodyweights per second ($BW \cdot s^{-1}$) respectively.

Upon completion of each experimental condition, the participants answered a questionnaire (as described by House et al)[17] which asked them to evaluate the comfort of the running shoes, military boots, and military boots with insoles, by marking a position on a line that ranged from very comfortable (+10) to very uncomfortable (–10).

Statistical Analysis

Statistical analysis of the GRF variables was undertaken using PASW Statistics 18 (IBM SPSS, Inc., 2009, Chicago, IL). Means and standard deviations were computed for all variables. Analysis of Variance (ANOVA) and subsequent post-hoc analysis (Tukey) were used to determine possible differences between footwear conditions with an alpha level of 5%. A Friedman test was used to analyze the questionnaire data and Spearman’s rank correlation test to examine possible relationships between subjective (questionnaire) and objective (GRF) data.

Results

Analytical data for all variables during walking are presented in Table 1. During walking, IPF was lower when participants wore their own running shoes than when wearing the military boots either with or without the insoles. Furthermore, MF was lower in running shoes than in the MBA and MBB conditions but it was not lower in running shoes than in the MB condition. This was despite there being a larger absolute difference between the running shoes and MB than between running shoes and MBA or MBB. This was due to the larger range (and therefore larger standard deviation) found in the MB condition for this variable.

Analytical data for conditions RS, MB, MBA and MBB during running are shown in Table 2; no significant differences were found for any of these variables.

The subjective comfort/discomfort data for each condition are presented in Figure 1 below.

All participants rated the running shoes as the most comfortable, and they were significantly different from other conditions (Friedman = 17.4, $p < 0.001$). Mean ranks for RS, MB, MBA and MBB were 3.9, 1.0, 2.7 and 2.4 respectively. The range of comfort-discomfort scores (–10 = very uncomfortable; 0 = neutral; 10 = very comfortable) for RS, MB, MBA and MBB were from 5 to 10, from –10 to 4, from –7 to 8 and from –8 to 7 respectively. The number of participants who rated the RS, MB, MBA, MBB conditions in the comfortable range (greater than 0) was 7 (100%), 1 (14%), 4 (57%) and 3 (43%) respectively. Alternatively, the number of participants who rated the RS, MB, MBA, MBB conditions in the uncomfortable range (less than zero) was 0 (0%), 9 (86%), 3 (43%) and 4 (57%) respectively. No significant correlations were found between comfort/discomfort data and GRF data. Spearman rank test correlation values are presented in Table 3.

Discussion

The aim of this study was to investigate the GRFs generated during walking and running while wearing running shoes (RS), military boots (MB), and military boots with two different shock-absorbing commercial insoles (MBA and MBB) in an attempt to understand the possible internal loading mechanics. The present data showed that during walking across all conditions, running shoes presented a lower GRF profile compared with military boots either with or without the shock absorbing insoles. In particular, impact peak force was approximately four times greater in the three military boot conditions compared with running shoes. However, despite the absolute values for maximum force, loading rate and push-off rate being higher for military boots than for running shoes, there were no significant differences between them. The values found for maximum force in both insole conditions (MBA and MBB) were found to be greater than in running shoes. The absence of a similar significant difference in the MB condition (despite higher absolute values) might have been due to the larger standard deviation found in the MB condition. Larger standard deviations were also found in the MB condition during the running trials for all GRF variables. These larger deviations in both forms of gait suggests that there is a wider range of individual adaptations to wearing military boots which means that for some individuals (i.e. those encountering the greatest decrease in GRFs), the insoles might be more worthwhile and have an important benefit.

During the running trials, the study's overall results showed that no significant differences existed across all variables while wearing the running shoe compared with the three boot conditions. This might have been due to the participants adopting different running styles to accommodate the different footwear conditions so that GRFs were minimized. In particular, research suggests that individuals adapt their running style to different shoe-surface interactions[18] so that changes in gait kinematics (e.g. footstrike pattern) occur to reduce impact variables, such as peak impact force, or any pain or discomfort experienced; it is possible that this may have occurred in the military boot conditions. Whatever the reason, there was no advantage to either wearing running shoes or commercial insoles when running in terms of reducing GRF magnitudes. These results differ from those of some previous research which did find reduced impact forces with some insoles in military boots.[8,15] The present study measured impact forces using a instrumented treadmill rather than the more commonly used runway methodology as it eliminated the risk of participants targeting the force plate or varying their speed. It is possible that the differences in findings were a result of these different methodologies and further research using instrumented treadmills is advised.

With regard to ratings of comfort, the findings of the present study suggested that commercially available insoles did not play a significant role in the perception of footwear comfort in the military boots. In particular, the results showed that even with an insole the military boots did not achieve the comfort perception of the running shoes. This is probably due to the fact that the military boot provided extra weight to the foot, is much more rigid, and its general design and construction have other priorities than comfort.[1,7] On an individual basis, all participants gave higher ratings to the two insole conditions than without the insoles, similar to earlier studies[17,19] but there was no significant difference overall and both insole conditions were still rated as uncomfortable by roughly half the participants. This suggests that the shock absorbance properties of the insoles were not sufficient to make the boots comfortable enough for walking and running across all individuals (as the running shoes were) and this is another aspect of fitting insoles which needs to be assessed on a case-by-case basis. The low comfort scores found for the insole conditions might be due to the other properties of the military boot which make it uncomfortable (e.g. its rigidity) and therefore cannot be overcome with an insole alone. The perception of comfort scores showed that all participants preferred walking and running while wearing a running shoe and this suggests that changes in military boot design, such as softer leather and wider shoe lasts could be beneficial.[20]

The results of the present study indicating that insoles did not have a significant role in comfort perception when wearing the military boot contrasts with the findings of other studies,[19,21] where boots with the best combination of shock absorbing properties and stability were rated the most comfortable by the participants. However, even in these studies[19,21] there was no association between the sensitivity of cushioning and the GRFs, which was supported by the present study's data where comfort ranking was also not related with any of the force variables measured. This would seem to suggest that a boot which feels comfortable does not necessarily have reduced GRF magnitudes, and therefore any risk of injury to the lower limb from impact forces needs to be assessed separately. While the lack of significance could be partly due to the limited number of participants, we would nonetheless suggest that the perception of comfort itself is not sufficient to provide evidence for the suitability of the insoles and for their promotion amongst recruits. Furthermore, since the insoles in the present study were rated under a very short-term trial, the clinical value of the present results is not certain; in particular, insoles which do make military boots comfortable on initial usage should be assessed over the course of many months of being worn to measure any depreciation in quality. The participants in the present study were required to run and walk for relatively short periods of time for each condition (4 minutes); this was to avoid fatigue or pain which could have been exacerbated by performing in unusual shod conditions. However, it is possible that longer bouts of running and walking will provide useful insights into cushioning and comfort variables in military boots and such future research is recommended.

The loss of manpower due to lower limb injury is a serious issue for professional armies. Basic infantry training has been changed in some armies in order to reduce the incidence of lower limb injury, for example with reduced marching.[20] Nonetheless, army personnel are still required to march often considerable distances on foot while carrying heavy loads. With regard to GRF variables, program modifications may be needed so that long-term hiking with pack and equipment are performed in military boots which resemble running shoes in terms of absorbance and comfort properties, rather than by just adding an insole to the military boot. However, care must always be taken with new boot design as more comfortable boots are not necessarily better for injury prevention.[22] The use of an instrumented treadmill for future studies on military boots is recommended due to the large number of footstrikes quickly available for analysis and the ability to record footstrikes from both right and left feet.

Conclusions

The present study illustrated that the military boots used by the Cypriot and Greek Army personnel with the use of the two specific insoles did not significantly influence impact peak forces during walking and running. Participants found the military boots uncomfortable and this was not significantly offset when using the insoles. Although commanders insist that recruits wear military boots in preparation for and during war and therefore there is a need to train in them beforehand, it should be noted that an injured recruit cannot fight as well as a healthy recruit. Therefore, because of inter-individual differences in GRF patterns, it is worthwhile assessing each recruit on an individual basis for the appropriateness of inserting insoles into military boots.

References

1. Davidson PL , Wilson SJ , Chalmers DJ , Wilson BD , McBride D : Examination of interventions to prevent common lower-limb injuries to the New Zealand Defense Force. Mil Med 2009 ; 174(11): 1196-202.
2. Franklyn-Miller A , Wilson C , Bilzon J, McCrory P : Foot orthoses in the prevention of injury in initial military training. Am J Sports Med 2010 ; 39(1): 30-7.
3. Havenetidis K , Paxinos T : Risk factors for musculoskeletal injuries among Greek Army officer cadets undergoing basic combat training. Mil Med 2011 ; 176(10): 1111-6.
4. Havenetidis K , Kardaris D , Paxinos T : Profiles of musculoskeletal injuries among Greek Army officer cadets during basic combat training. Mil Med 2011 ; 176(3): 297-303.
5. Kaufman KR , Brodine S , Shaffer R : Military training-related injuries: surveillance, research, and prevention. Am J Prev Med 2000 ; 18(3S): 54-63.
6. Schwellnus MP , Jordan G , Noakes TD : Prevention of common overuse injuries by the use of shock absorbing insoles. Am J Sports Med 1990 ; 18(6): 636-41.
7. Snyder RA , DeAngelis JP , Koester MC , Spindler KP , Dunn WR : Does shoe insole modification prevent stress fractures? A systematic review. Hospital Special Surg J 2009 ; 5(2): 92-8.
8. Dixon SJ , Waterworth C , Smith C , House CM : Biomechanical analysis of running in military boots with new and degraded insoles. Med Sci Sports Exerc 2003 ; 35(3): 472-9.
9. Razeghi M , Batt ME : Biomechanical analysis of the effect of orthotic shoe inserts. Sports Med 2000 ; 29(6): 425-438.

10. House CM , Waterworth C , Allsopp AJ , Dixon SJ : The influence of simulated wear upon the ability of shock absorbing insoles to reduce peak pressures during running when wearing military boots. Gait Posture 2002 ; 16(3): 297-303.
11. Withnall R , Eastaugh J , Freemantle N : Do shock absorbing insoles in recruits undertaking high levels of physical activity reduce lower limb injury? A randomized controlled trial. J R Soc Med 2006 ; 99(1): 32-7.
12. Ekenman I , Milgrom C , Finestone A , Begin M , Olin C , Arndt T , Burr D : The role of biomechanical shoe orthoses in tibial stress fracture prevention. Am J Sports Med 2002 ; 30(6): 866-70.
13. Larsen K , Weidich F , Leboeuf-Yde C : Can custom-made biomechanic shoe orthoses prevent problems in the back and lower extremities? A randomized, controlled intervention trial of 146 military conscripts. J Manipulative Physiol Ther 2002 ; 25(5): 236-31.
14. Milgrom C , Finestone A , Lubovsky O , Zin D , Lahad A : A controlled randomized study of the effect of training with orthoses on the incidence of weight bearing induced back pain among infantry recruits. Spine 2005 ; 30(3): 272-5.
15. Dixon S : Influence of a commercially available orthotic device on rearfoot eversion and vertical ground reaction force when running in military footwear. Mil Med 2007 ; 172(4): 446-50.
16. O’Leary K , Anderson Vorpahl K , Heiderscheit B : Effect of cushioned insoles on impact forces during running. J Am Podiatr Med Assoc 2008 ; 98(1): 36-41.
17. House CM , Dixon SJ , Allsopp AJ : User trial and insulation test to determine whether shock-absorbing insoles are suitable for use by military recruits during training. Mil Med 2004 ; 169(9): 741-6.

18. Nigg BM , Yeadon MR : Biomechanical aspects of playing surfaces. J Sports Sci 1987 ; 5(2): 117-45.
19. Mündermann A , Stefanyshyn DJ , Nigg BM : Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors. Med Sci Sports Exerc 2001 ; 33(11): 1939-45.
20. Finestone A , Milgrom C : How stress fracture incidence was lowered in the Israeli Army: a 25-yr struggle. Med Sci Sports Exerc 2008 ; 40(11 suppl): S623–9.
21. Williams KM, Brodine SK, Shaffer RA, Hagy J, Kaufman K: Biomechanical properties of infantry combat boot development. Naval health research center Report No 97-26, 1997; pp.1-22. The Defense Technical Information Center. Available at http//www.dtic.mil/dtic/tr/fulltext/u2/a331427.pdf; accessed August 30, 2012.
22. Arndt A , Westblad P , Ekenman I , Lundberg A : A comparison of external plantar loading and in vivo local metatarsal deformation wearing two different military boots. Gait Posture 2003 ; 18(2): 20-6.

Table 1. GRF data for each condition during walking

	Footwear condition			
Variable	**Running Shoes (RS)**	**Military Boots (MB)**	**Military Boots with Insole A (MBA)**	**Military Boots with Insole B (MBB)**
Impact Peak Force (BW)	0.11 ± 0.08 [a]	0.43 ± 0.04 [a]	0.41 ± 0.03 [a]	0.42 ± 0.06 [a]
Maximum Force (BW)	1.15 ± 0.04 [b]	1.25 ± 0.12	1.19 ± 0.05 [b]	1.21 ± 0.04 [b]
Loading Rate (BW·s^{-1})	7.60 ± 1.19	8.03 ± 0.87	7.86 ± 0.74	8.13 ± 0.89
Push-Off Rate (BW·s^{-1})	10.46 ± 0.50 [c]	10.47 ± 0.86	9.91 ± 0.63 [c]	10.06 ± 0.84

Impact peak force and maximum force are expressed in bodyweights (BW), and loading rate and push-off rate in bodyweights per second (BW·s^{-1}). *a = significant difference ($p < 0.001$) between RS and MB, MBA, MBB; b= significant difference ($p < 0.01$) between RS and MBA, MBB; c = significant difference ($p < 0.05$) between RS and MBA*

Table 2. GRF data for each condition during running

	Footwear condition			
Variable	**Running Shoes (RS)**	**Military Boots (MB)**	**Military Boots with Insole A (MBA)**	**Military Boots with Insole B (MBB)**
Impact Peak Force (BW)	1.21 ± 0.10	1.22 ± 0.19	1.10 ± 0.10	1.12 ± 0.19
Maximum Force (BW)	2.33 ± 0.14	2.40 ± 0.17	2.36 ± 0.13	2.42 ± 0.08
Loading Rate ($BW \cdot s^{-1}$)	23.91 ± 4.49	22.48 ± 4.80	21.67 ± 3.35	21.90 ± 2.38
Push-Off Rate ($BW \cdot s^{-1}$)	18.21 ± 2.49	18.43 ± 2.81	18.33 ± 2.36	18.41 ± 2.14
Impact peak force and maximum force are expressed in bodyweights (BW), and loading rate and push-off rate in bodyweights per second ($BW \cdot s^{-1}$).				

Table 3. Correlation analysis of key GRF variables with comfort scores during both running and walking.

	Comfort/discomfort response			
Ground reaction forces	**Running Shoes (RS)**	**Military Boots (MB)**	**Military Boots with Insole A (MBA)**	**Military Boots with Insole B (MBB)**
	Walking			
Impact Peak Force (BW)	–0.06	0.29	0.52	–0.11
Maximum Force (BW)	–0.69	–0.46	–0.28	0.25
Loading Rate ($BW{\cdot}s^{-1}$)	–0.13	–0.25	–0.34	0.09
Push-Off Rate ($BW{\cdot}s^{-1}$)	–0.13	–0.11	0.14	0.11
	Running			
Impact Peak Force (BW)	0	–0.54	–0.02	0.04
Maximum Force (BW)	0.24	–0.61	–0.57	–0.22
Loading Rate ($BW{\cdot}s^{-1}$)	–0.35	–0.36	–0.29	0.25
Push-Off Rate ($BW{\cdot}s^{-1}$)	0.33	–0.50	–0.65	–0.07

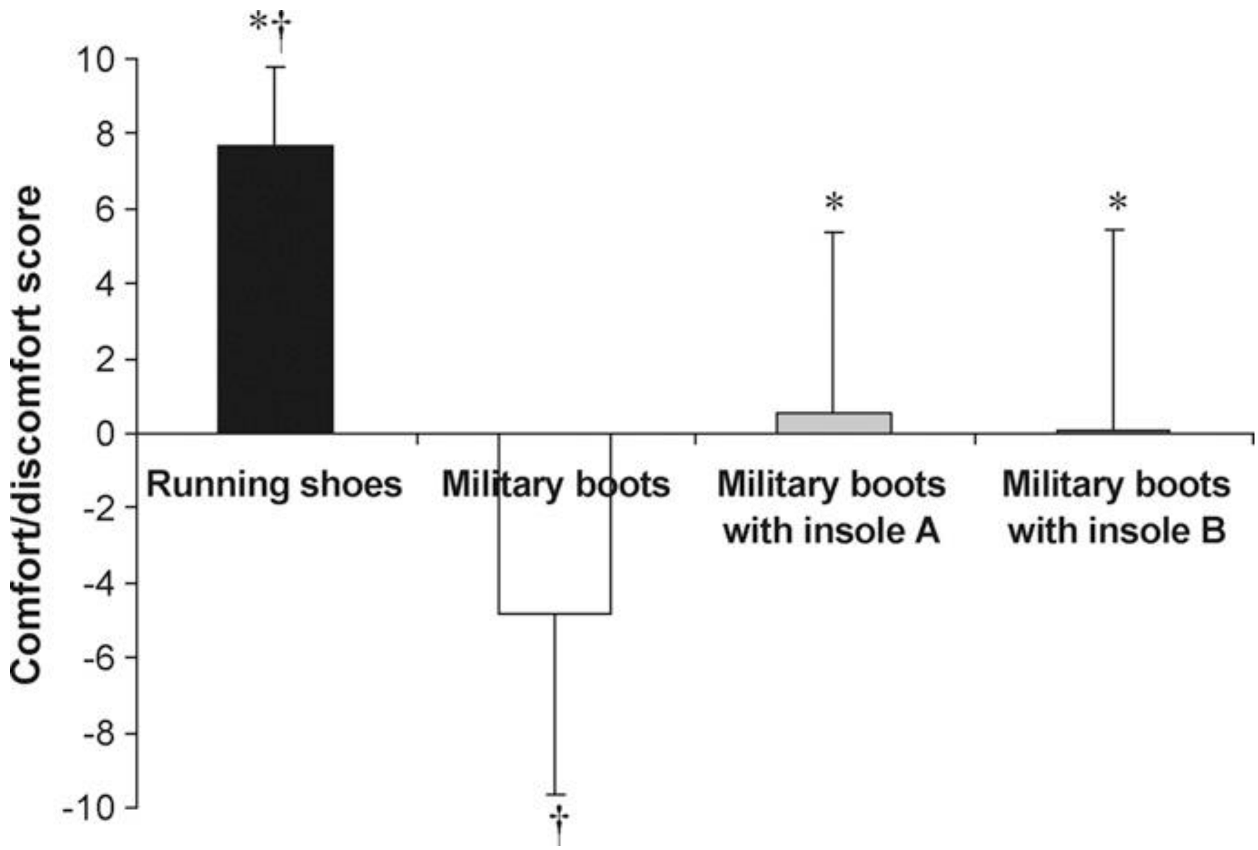

Figure 1. Average comfort results for RS and MBs without and with insole A (MBA) and B (MBB). * Indicates a significant difference between RS and MBA ($p < 0.05$) and MBB ($p < 0.05$) conditions, and † indicates a significant difference between MB and RS ($p < 0.001$) conditions.